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EFFECTS OF INCREASING THE MINIMUM SIZE LIMIT OR IMPOSING FISHING CLOSURES ON THREE SPECIES OF HAWAIIAN DEEPWATER SNAPPERS

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ABSTRACT

The likely effects of increasing the minimum size limit or imposing fishing closures (seasonal, areal) on three species of Hawaiian deepwater snappers, opakapaka (*Pristipomoides filamentosus*), onaga (*Etelis coruscans*), and ehu (*Etelis carbunculus*) were investigated using a computer simulation model. A range of values for sublegal fish mortality was addressed for changes in the minimum size limit. Probable effects of fishing mortality rate adjustments after imposing regulatory measures were also addressed. While regulatory measures can considerably increase spawning stock biomass (and therefore increase the spawning potential ratio, SPR), this benefit can be diminished or even converted to a net loss if the fishery responds with a substantial increase in the fishing mortality rate, particularly at high levels of sublegal fish mortality when minimum size limit is increased. Long-term yield generally decreases slightly for all regulatory measures, which may prompt the compensatory increases in fishing mortality rate.

INTRODUCTION

Recent concerns about possible recruitment overfishing of deepwater snappers in the Main Hawaiian Islands (Somerton and Kobayashi 1990b) have prompted investigation into the effectiveness of different management regulations for these species. While precise assessment of these stocks remains problematic because of data limitations (lack of recreational catch statistics, for example), there are simple indicators such as decreasing mean fish sizes and catch rates. The effectiveness of an increased minimum size limit or seasonal fishing closures was investigated for opakapaka by Somerton and Kobayashi (1990a, 1990c). These previous studies were simplistic because fishing mortality rate was assumed to remain constant after imposing a regulation, and sublegal fish mortality was only cursorily examined. The purpose of this study is to extend the previous analyses to two other deepwater snapper species and to examine (1) the effects of changes in fishing mortality rate after imposing a regulation, (2) the effects of variable sublegal fish mortality when minimum size limits are increased, and (3) the effects of areal fishing closures.

MATERIALS AND METHODS

Description of Simulation Model

Likely consequences of the different management scenarios were investigated using an age-structured, length-expressed computer simulation model. This model is simply a computer program that mimics, mathematically, the changes over time in age and size structure of a fish population due to growth and mortality processes. A full description of this model is available in Somerton and Kobayashi (1991). This approach provides a more precise estimate of population response to a fishery than the often used Beverton-Holt approximations (e.g., Huntsman and Waters 1987). The component of fishing mortality can be varied in the model to simulate the effects of changes in the minimum size limit or fishing closures. The model can be configured to mimic any species, provided that growth, natural mortality rate, length-weight conversion, and size at maturity parameters are available. A summary of parameters used in this analysis is shown in Table 1. These data include vonBertalanffy growth parameters (Ralston and Miyamoto 1983, Ralston, unpubl. data), natural mortality rates (Ralston and Kawamoto 1988), length-weight conversion parameters (Uchiyama et al. 1984), and sizes at maturity (Everson 1984, Everson et al. 1989, Kikkawa 1984). To accurately mimic the current situation in each fishery; i.e., the starting conditions of the model, two parameters must be known for each fishery: the fishing mortality rate and the size at entry to the fishery. Size at entry refers to the size at which 50% of the fish exposed to fishing gear die.

At larger sizes this value is assumed to approach 100%, where all fish exposed to fishing gear die. At smaller sizes this percent value is assumed to approach zero, where no fish exposed to fishing gear die. This pattern of size-dependent mortality can be caused by methods such as active targeting by fishermen, catch and release of small fish, or the size-dependent selectivity of fish hooks. Such a pattern contrasts with the natural mortality rate, which is assumed to apply to all fish equally over the entire size range. Modal (most common) sizes of the three snapper species in the main Hawaiian Islands (MHI) ranged from 1 to 3 lb during 1984-92, based on Honolulu auction survey data. As a conservative (worst case) estimate of the current size at entry for the computer simulation, 1 lb was chosen, which also happens to be the current minimum commercial size limit. The most problematic parameter in the computer simulation is the fishing mortality rate, which is both difficult to estimate and variable over time in the actual fisheries. Fishing mortality rate values for this analysis were derived from data presented in Ralston and Kawamoto (1988).

For all trials, the simulation model was first initiated with equilibrium conditions; i.e., a point at which the population is in balance with both the natural mortality rate and the current level of fishing mortality rate. At equilibrium, the population is at a stable size with no net gain or loss of individuals; gains due to recruitment and growth are exactly offset by mortality losses. A change in the fishery was then imposed to simulate the effects of a different minimum size limit or a fishing closure. The simulation model was then allowed to run until equilibrium was again reached. The two weight quantities tracked during the simulation were spawning stock biomass (SSB) and fishery yield. SSB is the total weight of mature fish left in the population, while fishery yield refers to total weight of all fish in the catch. Changes in SSB and yield were expressed in terms of changes from initial values:

$$\textit{Percent change} = \frac{\textit{Current value - Initial value}}{\textit{Initial value}} \times 100\%.$$

Yield in this analysis refers to yield per recruit and primarily corresponds to total annual yield, but can also correspond to changes in catch-per-unit of fishing effort (CPUE) assuming that the measure of fishing effort used in CPUE remains constant.

Increasing Minimum Size Limit

The effects of increasing the minimum size limit were investigated by changing the size at entry to the fishery. This analysis extends the work by Somerton and Kobayashi (1990a) by (1) analyzing ehu and onaga as well as opakapaka, and (2) evaluating the effects of a change in the fishing mortality rate after the implementation of a different size limit. Item (2) primarily addresses the possible effects of compensatory increases in fishing mortality rate after a size limit increase. However, as described in the next section, by reducing the fishing mortality rate, the possible effects of a **combined** size limit increase **and** fishing closure can be addressed. Size at entry for all three species was changed from 1 to 3 lb. Since 3 lb was apparently chosen with regard to the approximate weight at maturity for opakapaka, additional trials were run for onaga which matures at approximately 10 lb. No additional trials were run for ehu, which matures at approximately 1 lb. The computer simulation was run until equilibrium was achieved.

The degree to which sublegal fish experience fishing mortality was expressed as a value ranging from 0 to 1 representing the fraction of legal fishing mortality experienced by sublegal fish. For example, 0 represents the ideal scenario in which all sublegal fish are protected from fishing mortality. At the other extreme, 1 represents the worst case scenario in which the full level of fishing mortality experienced by legal fish is inflicted upon sublegal fish. Even assuming that all sublegal fish are released upon capture, the sublegal mortality fraction value is probably nonzero due to (1) inability to effectively target fishing activity away from sublegal fish, and (2) fatal trauma caused by hooking, handling, and pressure-related ailments. For lack of better information on what this actual fraction would be, 4 values ranging from 0 to 0.5 were run for each application involving fishing mortality rate changes. A full range of values from 0 to 1 was run for simple size limit increases from 1 to 3 lb. It should be noted that this simulation assumed complete release/discard of sublegal fish; i.e., only legal-sized fish were tabulated into catch-yield estimates.

Seasonal Fishing Closures

Seasonal fishing closures were investigated using the same technique as Somerton and Kobayashi (1990c). The duration of a seasonal closure was expressed in the simulation model as a reduced level of the fishing mortality rate (F). This new level of F was iteratively calculated using a Baranov catch equation to find the new F corresponding to the proportionally reduced original total annual catch. Iterative methods had to be used because the proportional reduction of fishing mortality rate only approximates the proportional reduction in total catch. For simplicity, catch was assumed to be uniformly distributed over the year; e.g., a 1-month closure reduces total annual catch by one-twelfth. Since it is known that certain months have consistently higher or lower catches, the effect of a closure of 1 month can be evaluated by (1) calculating that month's proportion of the total annual catch, (2) recasting that proportion into a simulated month (multiply by 12), and (3) examining the resulting closure duration in this analysis. For example, if the closed month actually accounts for a quarter of the total annual catch, the simulated impact would occur at a 3-month seasonal closure in this analysis. Since the seasonal fishing closure is only expressed as a reduction in fishing mortality rate, any compensatory increases in fishing effort that occur during the open season would directly offset any changes in SSB or yield, using our present computer simulation. However, even with compensatory increases in fishing effort, there may be potential gains in SSB or yield by protecting spawning fish, if the fishing closure coincides with spawning activity. This benefit cannot be presently quantified because of the lack of information on recruitment variability and its relationship to SSB; i.e., a spawner-recruit relationship. The presently used population model mimics a constant recruitment population with no spawner-recruit relationship.

Areal Closures

The potential effects of certain fishing area closures have not previously been addressed. However, the method used to simulate a seasonal closure can also be used to simulate an areal closure by assuming that reductions of total fishing area can correspond to proportional reductions in the total fishing mortality rate. Again, the simplifying assumption is that catch is uniformly spatially distributed, and reductions in total fishing area result in a proportional reduction in total catch. The responses are identical to the seasonal closure analyses, with the only difference being that reductions in fishing mortality rate correspond to a particular level of either (1) seasonal fishing closure durations, or (2) reductions in total fishing area. As with the seasonal fishing closures, there may be potential gains in SSB or yield if the protection of spawning fish in this area causes overall recruitment to increase. This benefit cannot be presently quantified due to lack of information on recruitment variability and its relationship to SSB; i.e., a spawner-recruit relationship.

RESULTS AND DISCUSSION

Time trajectories of SSB and yield changes for either a simple (i.e., no compensatory fishing mortality rate increase) 1- to 3-lb size limit increase or a 3-month seasonal closure are shown in Figure 1 for each of the three species. The 3-month seasonal closure plot can also be thought of as an areal closure of 25% of the total fishing area. Time trajectories vary greatly between species because of differences in growth, mortality, and size at maturity. For example, changes in onaga SSB are delayed for approximately 4 years after an increase in size limit. This is due to the larger size/older age at maturity for onaga; protected fish in the 1- to 3-lb range do not become part of the "mature fish pool" until they reach approximately 10 lb. SSB responses in opakapaka and ehu are more immediate and are particularly rapid in ehu, which has the smallest size/youngest age at maturity. For sake of brevity, all remaining analyses will focus on changes at equilibrium, operationally defined as conditions 15 years after imposition of a regulatory measure. As seen in Figure 1, most of the equilibrium changes are achieved after only 6 to 10 years. Since changes in SSB start at the origin (0, 0) on the graph, time trajectories from other analyses can be visualized using Figure 1 with the appropriately adjusted asymptotic endpoint (i.e., value at 15 years).

Equilibrium changes in SSB and yield due to an increase in the minimum size limit from 1 to 3 lb are summarized in Figure 2. These changes assume no fishing mortality rate adjustment after the size limit increase, but do explore the relationship of equilibrium changes with levels of sublegal mortality fraction ranging from 0 to 1. Both SSB and yield changes at equilibrium decrease at a near-linear rate with higher levels of sublegal mortality fraction. The maximal benefits in SSB are achieved at the lowest levels of sublegal mortality fraction, while higher levels of sublegal mortality fraction result in no net change in SSB. Higher levels of sublegal mortality fraction result in lower equilibrium yields. However, as mentioned earlier, this simulation assumes complete discarding of sublegal fish; therefore, the changes in yield are strictly caused by responses in population structure due to mortality of sublegal fish. If there is substantial retention of sublegal fish undergoing fishing mortality, the yield decreases in Figure 2 would be less severe and would approach zero change at higher levels of sublegal mortality fraction (essentially approaching the initial condition).

Isolating four levels of sublegal mortality fraction (0, 0.1, 0.3, and 0.5) and adding the potential for fishing mortality rate adjustment after a size limit increase from 1 to 3 lb results in the responses summarized in Figure 3. For reference, the three arrows indicate fishing mortality rate reductions corresponding to either 1-, 3-, and 6-month seasonal fishing closures or areal closures of 8%, 25%, or 50% of the total fishing area. Yield increases are generally possible by increasing the fishing mortality rate, but this comes at the expense of potential gains in SSB. For example, a doubling of the fishing mortality rate for opakapaka after a 1- to 3-lb size limit increase can result in a slight yield increase but, at best, will give no net change in SSB while, at worst, high sublegal mortality fraction will result in a substantial decline in SSB. As Somerton and Kobayashi (1990a) found, there are clear benefits to SSB assuming no change in the fishing mortality rate, even at moderate levels of sublegal mortality fraction. Maximal SSB increases are possible when a size limit increase is coupled with a fishing closure; however, this coincides with decreases in equilibrium yield.

Additional simulations for onaga with size limit increases to 5 and 10 lb were attempted with the same levels of sublegal mortality fraction and fishing mortality rate adjustments (Figs. 4A and 4B). Figure 4C summarizes all equilibrium changes to SSB and yield as a function of new size limit, assuming no fishing mortality rate adjustment. Compared to the other species, responses of onaga SSB and yield are relatively small, and slight gains in SSB are easily eliminated with small increases in fishing mortality rate unless the size limit is drastically increased. However, at this point, substantial decreases in yield are apparent.

The effects of seasonal fishing closures and areal closures of different duration are summarized in Figure 5. Similar to the size limit increases, onaga equilibrium SSB changes the least in response to a closure. Opakapaka equilibrium SSB increases the most, nearly double the magnitude of ehu and onaga equilibrium SSB changes. Onaga equilibrium yield decreases the most of the three species; however, all yield decreases are fairly small for seasonal closures of up to a few months and areal closures of 10-20%. SSB benefits from both types of closures can easily be eliminated if there are compensatory increases in fishing activity during the open fishing season or in the open fishing areas.

Economic Consequences

Pooley (1993) investigated the economic consequences of imposing different management regulations using the annual yield estimates from this study. The general approach to the economic analysis is to estimate the annualized present value of the fishery yield difference by comparing baseline (i.e., initial) yield with yield taken under the three management scenarios investigated: (1) a size limit increase to 3 lb with no change in the fishing mortality rate, (2) a size limit increase to 3 lb with a gradually increasing (5% per year) fishing mortality rate which levels off at a value 50% over the initial fishing mortality rate, and (3) a 3-month seasonal closure. Scenario (3) could also correspond to an areal closure of 25%. The sublegal mortality fraction was assumed to be zero for the economic analyses.

These management regulations would have three direct economic effects:

(1) revenue in the fishery would decline in the first years of the regulation as yield dropped (due to a portion of the fishable population being prohibited from sale), with a rebuilding schedule then developing;

(2) with the depressed revenue, price levels for bottomfish species would probably increase (Pooley, 1987);

(3) however, both the loss of smaller fish (1-3 lb) or the interruption of the bottomfish supply during the closed season would be expected to reduce price levels.

It is likely that the supply and demand effects (2) and (3) would roughly cancel each other out, leaving the decline in yield as the primary economic cost. It is also likely that, accompanying the declining yield, operating efficiency in the fishery would decline (because of increased search time, etc.) leading to increased operating costs or increased investments in fish-finding technology. These additional costs might lead to exit by some participants from the NWHI commercial fishery, while in the MHI the effect would probably be to reallocate the bottomfish fishery more towards semi-commercial, recreational, and subsistence fishermen. This particular effect has not been quantified.

The results of the economic analysis are shown in Table 2. They indicate that, using a 7.4% discount rate (the U.S. long-term bond rate as of July 1992) over a 14-year time horizon, the simple 3-lb size limit increase will result in lost revenues, on average, of $154,633 per year for opakapaka, $70,530 per year for onaga, and $27,571 per year for ehu. These revenues are based on 1991 estimates of total current fishery values of $936,569, $912,620, and $158,027, respectively, for the three species. The annualized revenue reflects an integrated cost or benefit per year over the time horizon studied; the revenue costs in the first few years will be much greater. Using the gradually increasing fishing mortality rate, coupled with the 3-lb size limit increase, the lost revenue is substantially less for opakapaka and ehu, and actually converts to a long-term economic benefit for onaga. The cost of the 3-month seasonal closure would lie between the two cost estimates of the 3-lb size limit increase for opakapaka and ehu but would be greater for onaga. An example of yield discounting over time and subsequent revenues are shown in Figure 6 for the opakapaka size limit increase with gradually increasing fishing mortality rate. It is noteworthy that, even though yield may equilibrate to higher-than-initial values (with corresponding higher-than-initial revenues on a single-year basis), this does not necessarily guarantee an eventual economic "catching up" or "breaking even" in the long term due to discounting (a measure of the changing value of money over time). This concept of "Present Value" (PV) is a technique used to evaluate long-term investments involving a series of cash flows into the future (Wilkes 1977). The basic principle is that money received in the future is less valuable than money received today, with the idea that people could invest today and acquire interest on the principal in the future. Thus, for this analysis, the magnitudes of lost or gained revenues and the length of time to break even (and if it is at all possible) rely greatly on the PV concept and the discount rate used, as well as the changes in yield. The 2.5% and 10% discount rates in Table 2 are intended to be bounding ranges; for application to a commercial fishing operation the market rate of 7.4% should be appropriate.

In summary, the biological effectiveness of any of the proposed management regulations depends a great deal upon largely unknown factors such as mortality of sublegal fish and adjustments in fishing effort allocation by fishermen. From the biological perspective, there is no clear "best" strategy; the selection of a management regulation should be carefully made with adequate consideration to the economic impact on the fishery, and the enforceability of such a regulation.

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Table 1.--Summary of parameters used in the computer simulation model. VB and LW refer to vonBertalanffy growth parameters and length-weight conversion parameters, respectively. The units for K, M, and F are years^{-1}. The units for L_∞ and L_m, the size at maturity, are cm FL. The units for t_0 are years. Length-weight conversion is as follows: $W=aL^b$, where W and L are weight in kg and length in cm FL, respectively.

	VB					LW		
Species	K	L_∞	t_0	M	F	a	b	L_m
Opakapaka	0.15	78	-1.67	0.30	0.30	2.87×10^{-5}	2.87	45
Onaga	0.12	111	-1.27	0.29	0.10	3.06×10^{-5}	2.84	66
Ehu	0.06	118	2.06	0.32	0.30	1.67×10^{-5}	3.02	30

Table 2.--Annualized revenues (PV dollars per year) of bottomfish management regulations analyzed over a 14-year time horizon. Costs are identified as negative numbers, benefits are identified as positive numbers. F refers to the fishing mortality rate. These revenues reflect integrated year-to-date costs or benefits.

	Discount rate		
	2.5%	7.4%	10.0%
Regulation Scenario	Annual economic cost or benefit		
3-lb size limit increase			
No increase in F			
Opakapaka	$ -133,796	$ -154,633	$ -166,473
Onaga	$ - 64,016	$ - 70,530	$ - 74,297
Ehu	$ - 24,468	$ - 27,571	$ - 29,804
3-lb size limit increase			
50% increase in F			
Opakapaka	$ - 40,860	$ - 64,704	$ - 78,789
Onaga	$ 121,006	$ 102,590	$ 92,872
Ehu	$ 8,787	$ - 13,508	$ - 16,081
3-month seasonal closure			
Opakapaka	$ - 89,731	$ - 97,605	$ -101,663
Onaga	$ -163,944	$ -168,845	$ -170,884
Ehu	$ - 13,518	$ - 14,989	$ - 15,867

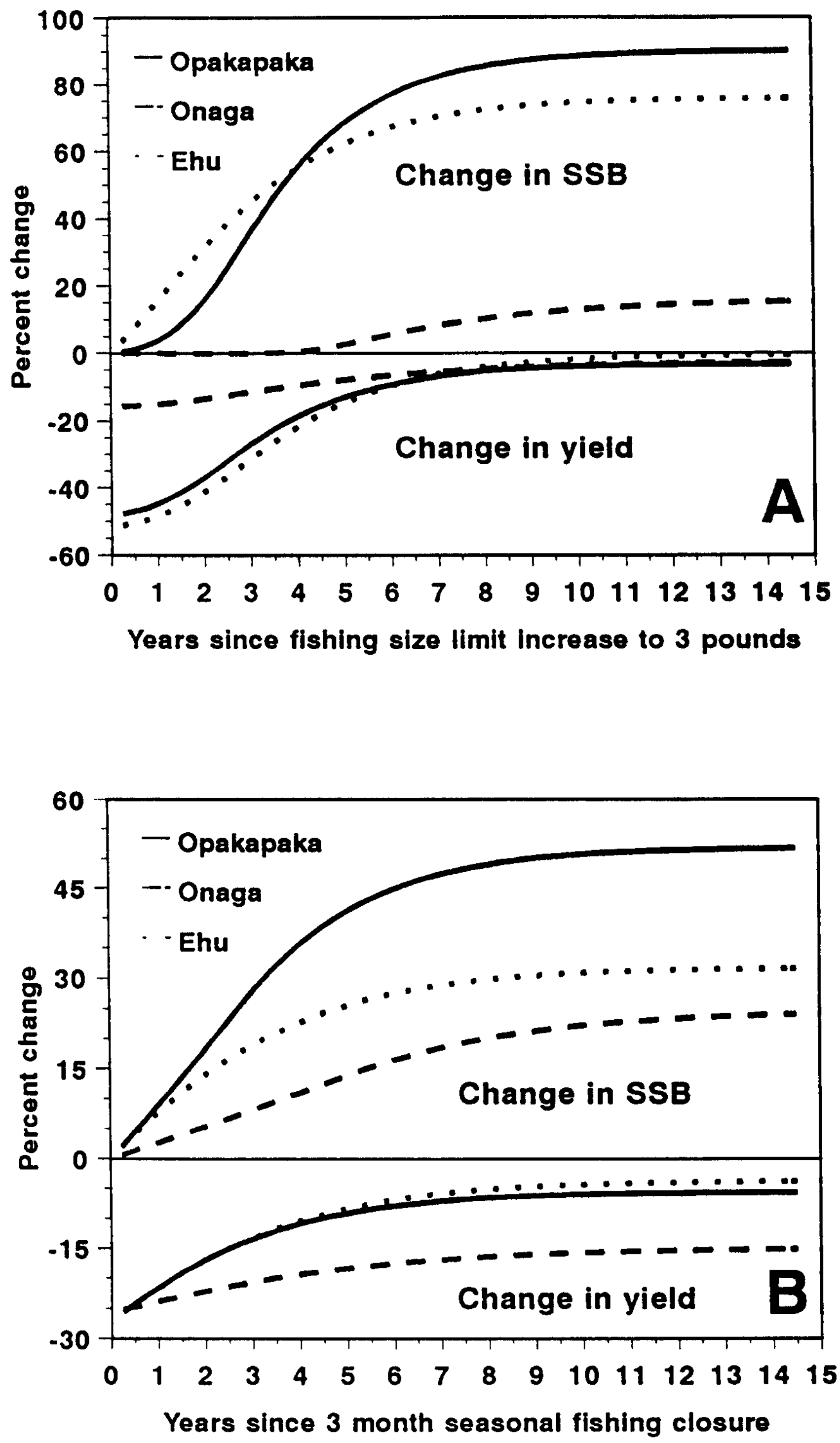


Figure 1.--Time trajectories of opakapaka, onaga, and ehu spawning stock biomass (SSB) and yield changes after a 1- to 3-lb fishing size limit increase (A) or a 3-month seasonal fishing closure (B).

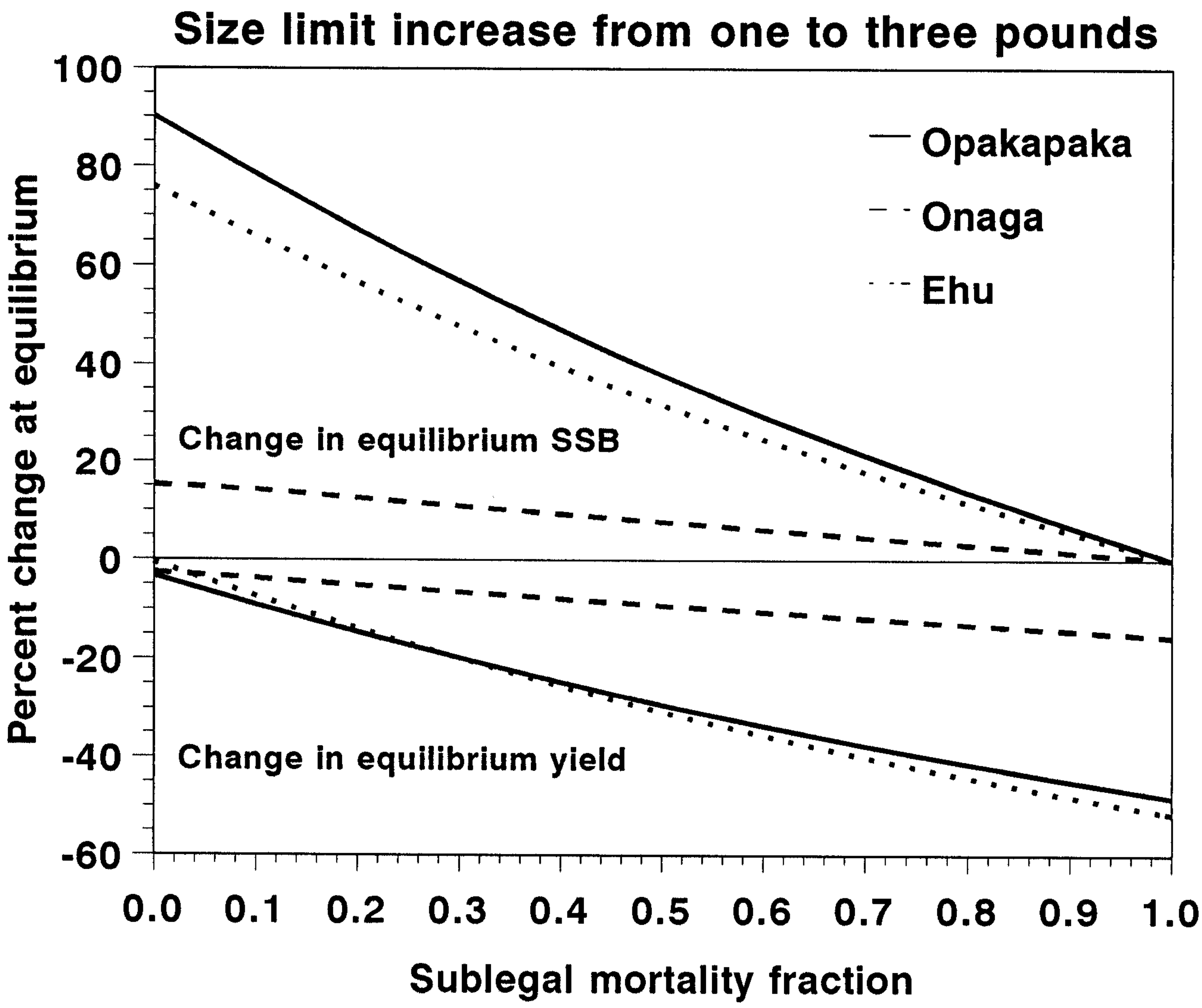


Figure 2.--Equilibrium changes in opakapaka, onaga, and ehu SSB and yield after a fishing size limit increase from 1 to 3 lb at different levels of sublegal mortality fraction.

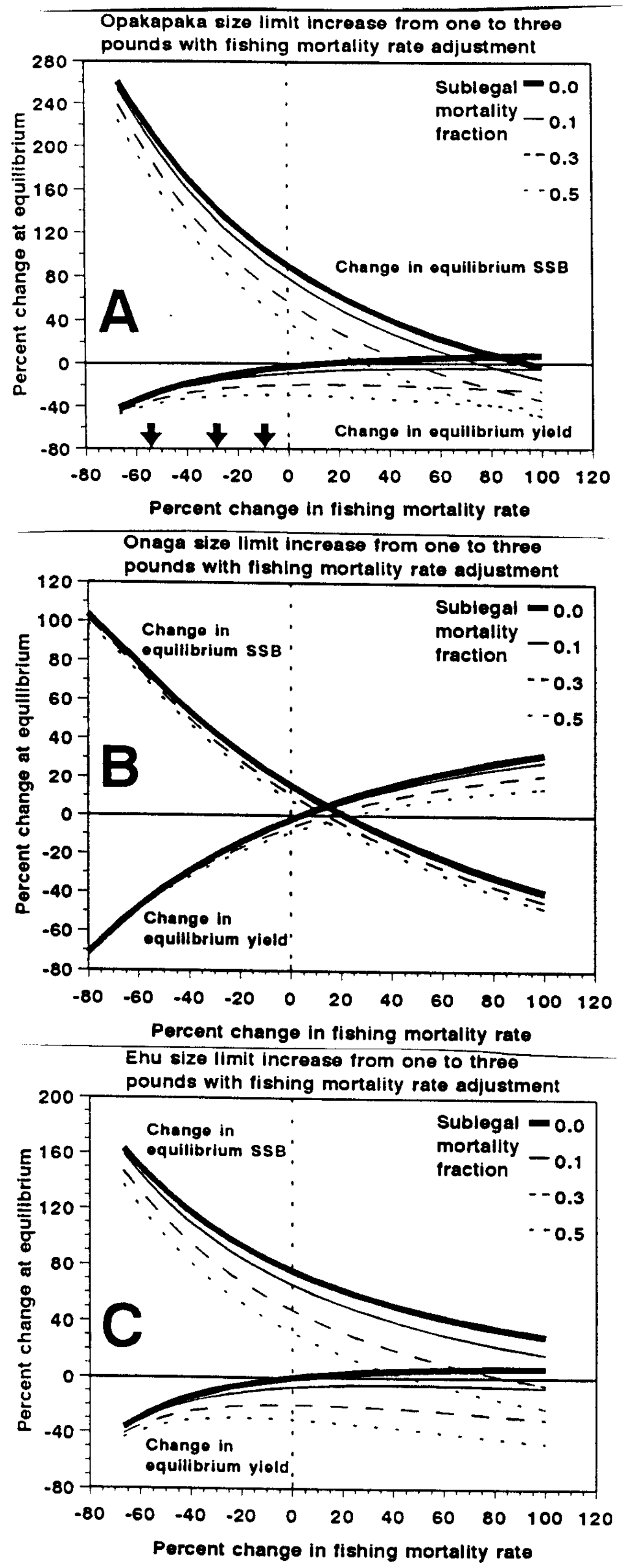


Figure 3.--Equilibrium changes in opakapaka (A) onaga (B), and ehu (C) spawning stock biomass (SSB) and yield after a fishing size limit increase from 1 to 3 lb with fishing mortality rate adjustments and 4 levels of sublegal mortality fraction. The three arrows, from left to right, indicate fishing mortality rate reductions corresponding to either 1-, 3-, and 6-month seasonal fishing closures, or areal closures of 8%, 25%, or 50% of the total fishing area.

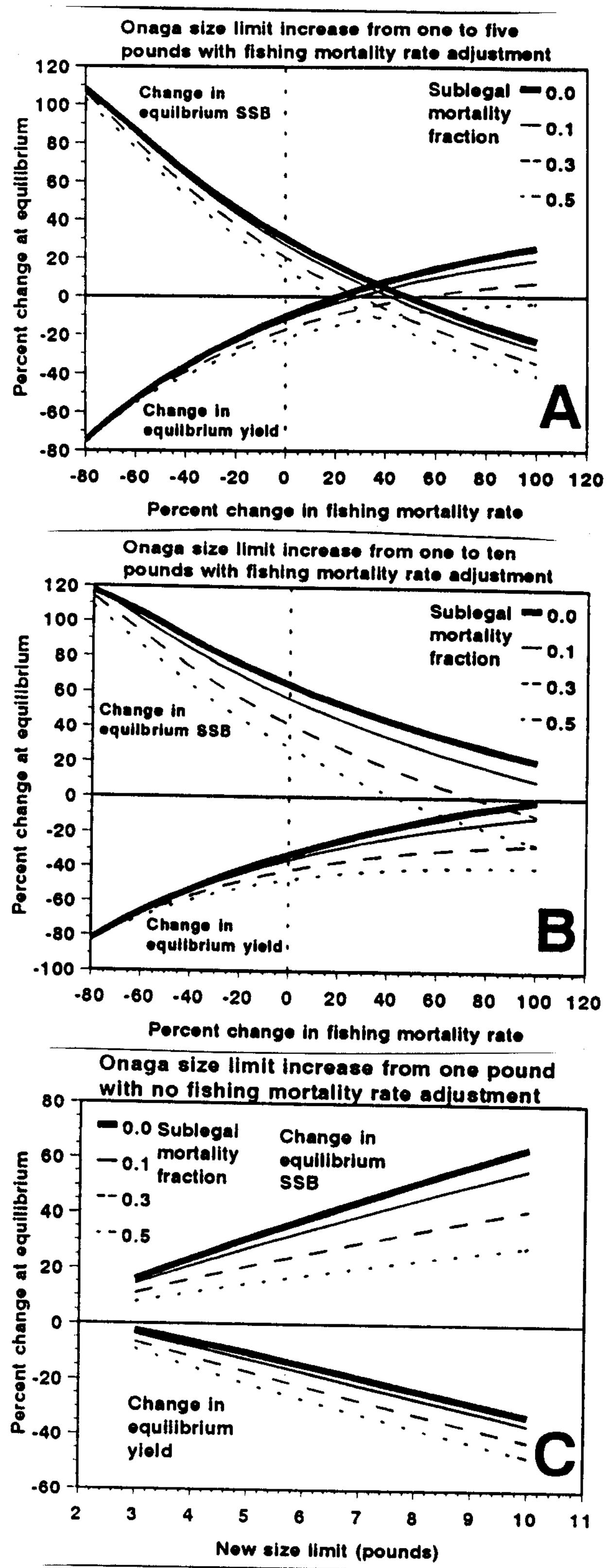


Figure 4.--Equilibrium changes in onaga spawning stock biomass (SSB) and yield after a fishing size limit increase from 1 to 5 lb (A) or 1 to 10 lb (B) with fishing mortality rate adjustments and 4 levels of sublegal mortality fraction, and summary of equilibrium changes at different levels of new fishing size limit, assuming no fishing mortality rate adjustments (C).

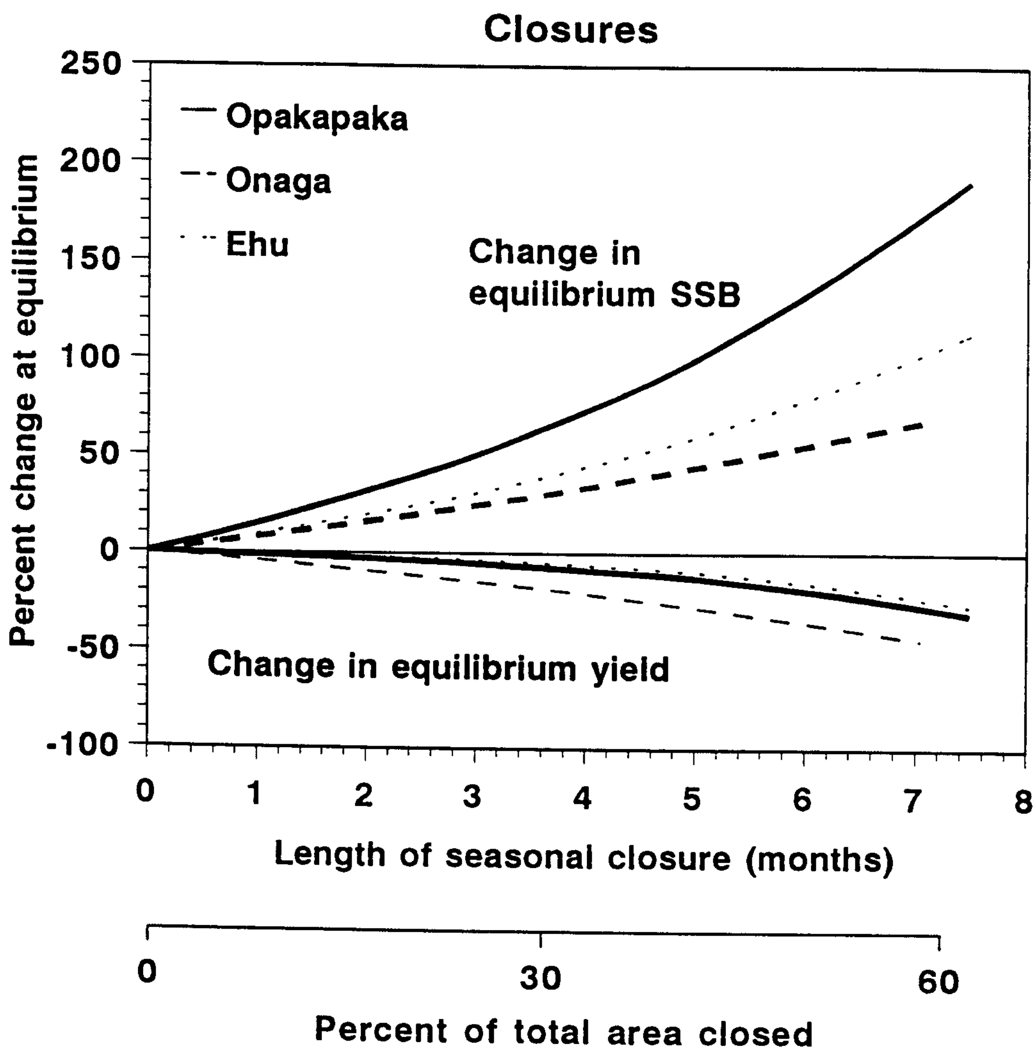
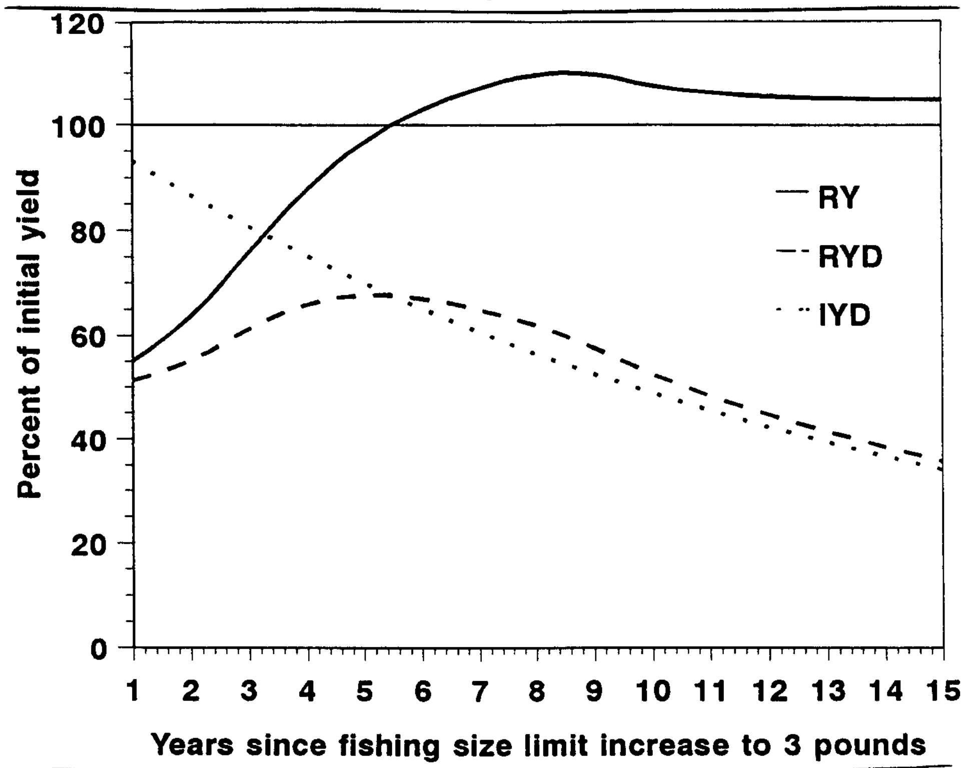


Figure 5.--Equilibrium changes in opakapaka, onaga, and ehu spawning stock biomass (SSB) and yield after a seasonal fishing closure, or an areal fishing closure.



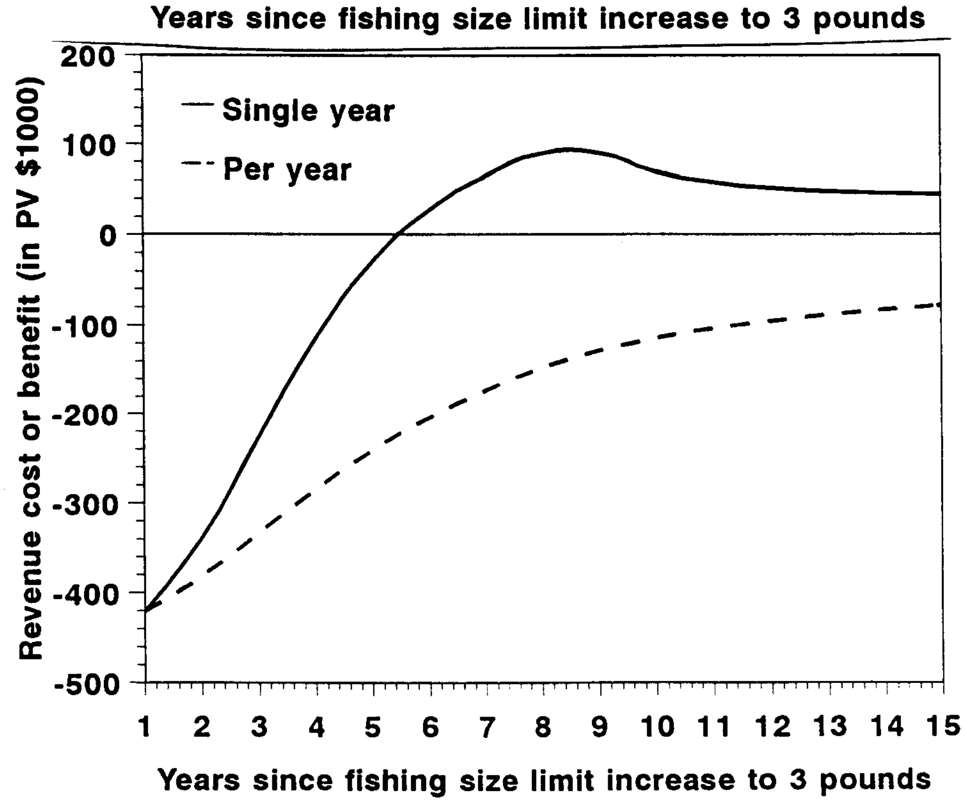


Figure 6.--Time trajectories of opakapaka yield expressed as a percent of initial undiscounted yield (upper) and corresponding revenues expressed in PV thousands of dollars (lower). RY and RYD refer to undiscounted and 7.4% discounted regulatory yield, respectively, after a size limit increase to 3 lb and a gradually increasing fishing mortality rate. IYD refers to 7.4% discounted initial yield. Single-year revenue refers to a cost (negative) or benefit (positive) calculated for that year only, relative to the initial revenue. Per-year revenue refers to a cost or benefit on an integrated year-to-date basis. Horizontal solid lines refer to initial yields and revenues.